Metacognitive strategies in modelling: comparison of the results achieved with the help of different methods

Estratégias metacognitivas em modelação: comparação dos resultados alcançados através de diferentes métodos

Katrin Vorhölter
Universität Hamburg
Germany
katrin.vorhoelter@uni-hamburg.de

Alexandra Krüger
Universität Hamburg
Germany
alexandra.krueger@uni-hamburg.de

Abstract. Metacognition seems to have a great influence on modelling processes and the development of modelling competencies. In contrast to the assumed importance, a relatively small number of studies have been conducted so far, as metacognition is a rather complex concept and the measurement of students' usage of metacognition is rather challenging. As part of the project, the use of metacognitive strategies when working on modelling tasks, as well as students' attitudes towards using them, were measured and evaluated using self-assessment questionnaires and interviews in form of stimulated recalls. In this paper, the outcome of the different methods will be compared and complemented by the analysis of the videotaped working process as a third data source. For this purpose, the self-assessments regarding the use of metacognitive strategies as well as statements in the interview of two students are considered as examples. Conclusions about the different methods and outcomes will be drawn.
Keywords: modelling; metacognitive strategies; planning; students' perspectives; measurement of strategies; self-assessment.

Resumo. A metacognição parece ter uma grande influência nos processos de modelação e no desenvolvimento de competências de modelação. Em contraste com a importância que lhe é atribuída, um número relativamente pequeno de estudos tem sido conduzido até agora, uma vez que a metacognição é um conceito bastante complexo e a medição da utilização da metacognição pelos estudantes é bastante desafiante. Como parte do nosso projeto, a utilização de estratégias

Quadrante: Revista de Investigação em Educação Matemática 30(1) 178-197
https://doi.org/10.48489/quadrante.23653
Received: February 2021 / Accepted: June 2021

metacognitivas em tarefas de modelação, bem como as atitudes dos estudantes em relação à sua utilização, foram medidas e avaliadas, utilizando questionários de autoavaliação e entrevistas baseadas na retrospetiva estimulada. Neste artigo, o resultado dos diferentes métodos será comparado e complementado pela análise do processo de trabalho gravado em vídeo, como uma terceira fonte de dados. Para este efeito, as autoavaliações relativas à utilização de estratégias metacognitivas, bem como as declarações feitas nas entrevistas por dois estudantes são consideradas como exemplos. Serão tiradas conclusões sobre os diferentes métodos e resultados.
Palavras-chave: modelação; estratégias metacognitivas; planificação; perspetivas dos alunos; medição da utilização de estratégias; autoavaliação.

Introduction

In recent years, much research has been done on the topic of modelling competencies. While in the beginning the focus was on the conceptualization of modelling competencies as an amalgamation of several facets, in recent years the focus has been on the effective promotion of these competencies. Mostly, this has been limited to the development of so-called sub-competencies of modelling. For this purpose, different tests have been developed, with the help of which the development of the sub-competencies has been surveyed in various intervention studies (cf. Hankeln, Adamek, & Greefrath, 2019; Kaiser & Brand, 2015).

However, modelling competencies as conceptualized for example by Maaß (2006) do not only include the sub-competencies. Rather, due to the complexity of the problems, metacognitive strategies have an effect on the development of modelling competencies and on the processing of modelling problems. Since in everyday school life working on modelling problems is usually not done by individual students on their own, but in small groups, not only individual metacognitive strategies, but especially metacognitive group strategies are of importance.

Despite the importance of metacognitive strategies during modelling activities research on metacognitive modelling strategies is still in its beginnings. One reason for this is the complexity of measuring metacognitive strategies, resulting from the complexity of metacognition as a cognitive process as such, resulting in methodical complexity. Thus, in the following we will introduce the concept of metacognitive modelling strategies and possible methods for assessing these. Our aim is to compare the outcome of different instruments and methods used within the MeMo project (Vorhölter et al., 2019), outline the advantages and disadvantages of the methods and give recommendations for further development.

Theoretical background

The question of how modelling competencies can best be promoted in the classroom is not easy to answer. Various research projects usually only focus on specific aspects. One reason for this is that working on a complex, reality-based problem requires not only mathematical knowledge, but also extra-mathematical knowledge and translation processes (Blum, 2015). If the modelling problems are worked on in small groups, competencies in cooperation and communication are also added to a greater extent. Thus, in the following we will show which competencies are necessary to solve a specific modelling problem. According to the topic of this paper, we focus on the area of metacognitive modelling strategies, which are necessary to reach a solution in a group in a collaborative and goal-oriented way. Furthermore, we present empirical findings on the influence and importance of metacognitive modelling strategies and point out the difficulties in researching them.

Metacognitive strategies as part of modelling competencies

Working on complex modelling problems always poses challenges for students. According to Kaiser (2007, p. 111), the competencies required in such modelling problems include in particular

- competencies to understand real-world problems and to construct a reality model;
- competencies to create a mathematical model out of a real-world model;
- competencies to solve mathematical problems within a mathematical model;
- competency to interpret mathematical results in a real-world model or a real situation;
- competency to challenge solutions and, if necessary, to carry out another modelling process.

These competencies, also referred to as modelling sub-competencies (e.g., Kaiser & Brand, 2015), are those that are needed to move from one step in a modelling cycle to the next. Other theoretical distinctions of modelling sub-competencies result from different views of the modelling process; in empirical studies, sometimes the specific sub-competencies are combined (cf. Hankeln, Adamek, & Greefrath, 2019; Kaiser & Brand, 2015). We exemplify those sub-competencies by means of an example (Figure 1).

Initiative for the Rainforest

In 2002, 2003, 2005, 2006 and 2008 the brewery "Krombacher" carried out the following initiative in cooperation with the WWF (World Wildlife Foundation) for 3 months each year:

For every crate of Krombacher beer sold, one square metre of rainforest in Dzanga Sangha (Central African Republic) is sustainably protected.

Study the impact of this action on global rainforest deforestation.

For your information: Every day approx. 356 km² of rainforest are cleared or burned down worldwide, of which approximately 93 km² alone are in Africa. Germans drink an average of 107 litres of beer per person per year.

Figure 1. Modelling problem "Initiative for the Rainforest", adapted from Leiss, Möller, and Schukajlow (2006)

For working on this modelling problem, students are asked to assess the impact of the brewery's advertising campaign on the sustainable protection of the rainforest. In doing so, students

- have to understand that they are asked to examine the impact of the campaign. They have to identify important information out of the text. To discover missing information, they have to make reasonable assumptions about necessary data (such as market share of the brewery, how many litres are in one crate, the distribution of beer consumption over the year and the inhabitants of Germany),
- have to make sense of this data, which includes deciding which values to use in the case of different assumptions for individual variables (for example market share of the brewery or distribution of beer consumption over the year),
- have to establish relationships between the identified variables in order to generate a mathematical model in the form of equations,
- have to solve the equations that have been set up, and finally
- have to interpret the data in the light of the assumptions, which particularly relates to the brewery's market share in this task.

However, modelling sub-competencies are important but not sufficient for efficient and goal-oriented processing. According to Maaß (2006), further competencies that affect the entire modelling process are necessary. Like Blum (2015), she counts metacognitive strategies among these.

Metacognitive strategies in general are used to control the learning or working process and are usually divided into planning strategies, monitoring and regulation strategies, and evaluation strategies. In some cases, they are supplemented by orientation strategies, which serve to identify learning requirements and available resources (e.g., Efklides, 2008; Schraw

& Moshman, 1995; Stillman & Galbraith, 1998). Thus, metacognitive modelling strategies include:

1. *Strategies that serve orientation*. Especially the identification of available resources can be helpful. These are time resources as well as the available material and research possibilities. The more significant, the more complex the problem is and the more time is available to work on it. For working on the modelling problem shown in Figure 1 in class, students should be aware of the conditions set by the teacher. Thus, these strategies concern not only the time available but also the requirements of how results should be presented, the extent to which work should be done in groups, which sources may be used for research and whether the teacher will provide supplementary material if necessary.
2. *Strategies for planning work processes*, taking into account the specific requirements of the modelling problem posed and the people involved. The established plan does not have to cover the entire solution process from the beginning but can initially contain only the first steps with the intention to plan the further steps in the later course. Concerning the Rainforest-Problem, students thus have to identify subgoals for example the calculation of the area protected by the campaign and allocate who takes over the research of which values. They have to decide to what extent they want to work together or share work and which sources they want to use for research.
3. *Strategies for monitoring and* - if necessary - *regulating the work process*. These refer to both a person-related level and a content-related level. Thus, for working on the rainforest problem, students are asked among others to make sure that everyone understand the single steps of the developed plan and agree on values for further calculation.
4. *Strategies for evaluating and assessing the modelling process* with the aim of optimizing the process next time. These also refer to a person-related level as well as to a content-related level and always have a reflexive as well as prospective component. Concerning the Rainforest-Problem, especially reflecting on the distribution of tasks and bringing together the results as well as the usage of heuristic strategies like dividing the problem in subproblems and considering special situations should be part of the evaluation.

According to Veenman (2011b), metacognitive strategies can be learned and used consciously at first, but executed automatically over time. Nevertheless, these automated actions are no less metacognitive in origin and come back into consciousness when a problem is identified. Therefore, these are often referred to as metacognitive behaviour (e.g., Stillman & Galbraith, 1998).

The use of metacognitive strategies for the individual learning and problem-solving process therefore depends also on other factors, some of which are situational. Weinert (1984) claims that metacognitive strategies are only used and that the usefulness of their

use is only seen when the tasks to be processed are at a subjectively medium level of difficulty. These situational factors also include the circumstance whether the task to be worked on has to be solved alone or in a group. If the latter is the case, not only individual metacognition but especially social metacognition is of great importance for the effective and goal-oriented processing of the task.

For a long time, the concept of metacognition was considered only for individuals. Since the late 1990s, the concept of social or group metacognition has been introduced in addition (e.g., Chalmers, 2009; Goos, Galbraith, & Renshaw, 2002). In general, social metacognition subsumes all those processes that contribute to goal-directed and effective task processing during cooperative work processes (Vauras, Iiskala, Kajamies, Kinnunen, & Lehtinen, 2003; Volet, Summers, & Thurman, 2009). Only if students communicate with each other and coordinate their actions, explain their ideas to each other, and externalize their thoughts, they can share their knowledge and expertise (Artzt & Armour-Thomas, 1992; Chalmers, 2009; Cooke, Salas, Kiekel, & Bell, 2004; Goos, 2002; Rogat & Adams-Wiggins, 2014). Accordingly, both the individual metacognitive competencies of all group members and the factors of social metacognition are important for goal-directed task processing in small groups. However, only few empirical findings exist in the field of mathematical modelling.

Empirical results concerning metacognitive modelling strategies

As stated above, research in metacognitive modelling strategies is still not widespread, although the impact of the usage of these strategies on modelling processes is not doubted (Blum, 2015). Fundamental findings were obtained by Stillman's group. In a first step, Stillman and Galbraith (1998) reconstructed metacognitive strategy knowledge in modelling problems and found in a study with 11 pairs of students that they invested a lot of time in the phases of orientation (understanding the problem, assessing the difficulty and probability of solution) and execution (monitoring and regulation of the process), less in the phases of planning (especially planning of goals and subgoals) and evaluation. They found that metacognitive strategies were used in all phases of the modelling process, and that the groups that invested less time in orientation and correspondingly more in the area of monitoring and regulation were particularly successful.

In another study, Stillman (2004) identified both cognitive and metacognitive strategies used by students when working on application tasks and clarified relationships between the use of cognitive and metacognitive strategies. Further, she reconstructed that the use of metacognitive strategies can lead to overcoming problems which often occur in form of red-flag situations. These were first identified in problem solving processes by Goos (2002) and later adapted by Stillman (2011) for modelling. The subsequent actions can be classified as appropriate or inappropriate. One of these actions (metacognitive blindness) was further conceptualized by Ng (2010) for metacognitive behaviour in groups by introducing the

notion of partial metacognitive blindness. The term refers to the case where some members of the group recognize a problem situation, but they are unable to convince the other group members of the need to respond to this problem.

In a later study, Stillman (2011) differentiated productive metacognitive behaviour into metacognitive strategies that (a) involve recognizing the need to use cognitive strategies, (b) lead to conscious selection of cognitive strategies, and (c) ensure successful use of cognitive strategies. The use of the three strategy variants depends on students' experience and knowledge of metacognitive strategies.

The relationship of metacognitive strategies and modelling competencies of students was investigated by Schukajlow and Leiß (2011): The evaluation revealed no significant correlation between students' self-reported metacognitive strategies on the one hand and mathematical modelling competencies on the other. In a similarly designed study, Schukajlow and Krug (2013) analysed the influence of being asked to develop multiple solutions on the use of planning and monitoring strategies. They found that this task had a greater impact on the number of strategies students used than the teacher's prompt. However, in both studies metacognitive strategies were measured independent of a concrete work process.

In the MeMo project (Vorhölter et al., 2019) the development of students' metacognitive strategies during an intervention study in regular classrooms was researched. A total of approximately 500 students from 19 classes in grades 9 and 10 (ages 14-16) were involved in the project. These were divided into two groups, working on the same six modelling problems which were constructed for 90 minutes. One group was promoted to metacognitive strategies, while the other group focused on the mathematical procedures used when working on the task. The modelling problems had different factual contexts and were related to different mathematical subfields such as volumes, calculation of triangles, and terms and functions. The elicitation of metacognitive strategies took place in two ways: The processing of the first modelling task (hot air balloon, see Vorhölter, 2018) was filmed in approximately 50 small groups. Following the completion of the modelling problem, the students were given a questionnaire, with the help of which they were to individually indicate self-assessments on a 5-point Likert scale (1 = no agreement to 5 = full agreement) related to metacognitive individual and group strategies used. In addition, selected students were asked about their views on metacognitive strategies using the method of stimulated recall (Gass & Mackey, 2000) afterwards. They were shown, among other things, video scenes from their small group work. This procedure was repeated after about half a year with reference to the 6th and thus last processing of the modelling problem presented in Figure 1 (for detailed descriptions of the whole project see for example Vorhölter, 2019; Vorhölter et al., 2019).

The students' self-assessments regarding the use of metacognitive strategies were evaluated separately for individual and group strategies. For the individual strategies, three measurement-invariant factors were identified for all subsamples (both comparison groups and measurement times). These factors refer to the planning of task processing, the control of the working process, and the regulation of this process. With respect to the group strategies, three factors could also be empirically reconstructed, which, however, were subdivided into strategies for a smooth process, for the regulation when problems occur, and for the evaluation of the working process, as suggested by the theory. A before-after comparison of the factor scores of the individual strategies showed that these fell rather than rose (although not to a significant degree) in relation to all factors and in both groups. The corresponding comparison of the factor scores of the group strategies revealed a significant change only for the group strategies for evaluation and only for the intervention group.

In addition to the students' self-assessments, the interviews conducted with the students were available as a further data source. With the help of the case-oriented qualitative content analysis according to Kuckartz (2019), a typology with student types could be reconstructed from the conducted student interviews, which differ in the attitude and the reconstructed triggers of the metacognitive strategy use in mathematical modelling from the student perspective. As a result, six different types could be reconstructed, which differed in their beliefs regarding the use of metacognitive strategies. The poles here are the "convinced metacognitive type" (characterized by its flexible use of metacognitive strategies, meaning that this type reacts to external triggers with the use of metacognitive strategies, but also uses self-initiated metacognitive strategies, and reflects on the use of metacognitive strategies by naming positive effects of the use) and the "distanced metacognitive type" (characterized, besides a described lack of use of metacognitive strategies, by the fact that representatives of this type do not want to use metacognitive strategies). During the study, it became apparent that it was useful to consider the different metacognitive domains of planning, monitoring/regulating, and evaluating strategies separately, as students' perspectives on the three domains varied considerably. Furthermore, a differentiation between metacognitive individual and group strategies could not be made based on the students' statements in the interview. Therefore, the classification primarily refers to the metacognitive group strategies used (Krüger, 2021).

It becomes clear that an increase in the self-determined nature of the use of metacognitive strategies is definitely discernible from the interviews, whereas this conclusion cannot be drawn from the self-evaluations in the questionnaires, thus highlighting the methodological discussion and Blum's (2015, p. 88) claim:

> There are a lot of empirical results concerning the effects of using strategies, mostly encouraging, some also disappointing. One of the problems in these empirical studies is: how to measure strategy knowledge, on the one hand, and strategy use,

on the other hand, and another problem is how to reliably link students' activities to their strategies.

Measuring metacognitive modelling strategies

In general, methods for measuring metacognitive strategies are usually distinguished in offline and online-methods. Offline-methods like prospective or retrospective interviews or questionnaires or stimulated recall on the other hand rely on students' self-reports. With these methods there is the risk that students are either unaware of the strategies used and therefore do not indicate the use of them, or that the questions or items will lead students to answer the questions based on their metacognitive knowledge, but not on their use of strategies (Veenman, 2011a). However, questionnaires are often used to measure metacognition as they are less time-consuming and costly (Ohtani & Hisasaka, 2018; Schellings, 2011). When developing such questionnaires, both individual and group metacognitive strategies must be considered. The questionnaire in the MeMo project was designed to distinguish between the use of metacognitive individual and group strategies on the one hand. Furthermore, only those strategies were retrieved that were not specific to a particular modelling problem. In order to measure actual strategies used rather than knowledge, the questionnaires were filled out directly after a task and the students were asked to indicate which strategies they had used during the task. For detailed information see Vorhölter (2017).

On the other hand, the usage of online methods like thinking aloud, observation, eye-movement analysis and log file registrations have the great advantage that students are not disturbed while working on the given task and one measures what they actually do – not what they think they should or would do. Especially the method of thinking aloud is often used for measuring metacognitive activities (Veenman & Elshout, 1999) as it is considered to be fairly reliable. However, methods like thinking aloud and observation only lead to reliable results, if students are able and motivated to verbalise all their thinking. Neither activities and behaviours that are automatized and therefore do not occupy space in the working memory, nor thoughts during phases of group work can be measured (Schellings, van Hout-Wolters, Veenman, & Meijer, 2013). Thus, online methods are mainly used for measuring the usage of individual metacognition.

In addition to the aforementioned questionnaire, the MeMo project also used a stimulated recall. This method can be formally assigned to the offline methods, since the students' views were assessed after the modelling problem had been completed. However, according to the method of stimulated recall, the students were shown video scenes from their own editing process and were asked to express what they had thought during the working process. The purpose of this was to get them to say what they had been thinking during the working process, thus combining the necessity of retrospective interviews with the advantages of the online methods (Vorhölter, 2017).

The quality of online and offline methods has been compared in several studies, mainly comparing questionnaires and think-aloud protocols (Schellings et al., 2013). Results show that self-reports are often found to be less reliable, as correlations between metacognition measured by self-report and by other methods are usually not very high. Thus, students' ability to provide information about the strategies they used is doubted. This result confirms Schraw's positioning expressed earlier in relation to the target parameters of an investigation (2009, p. 415):

> I take the position that different outcome measures provide different types of information that complement one another. While some outcome measures are better suited for specific research questions, it is not the case that one measure is best in all situations. I propose that it is essential to understand different types of judgment measures and to use them appropriately to pose and answer useful research questions.

Research questions

As presented above, within the Memo project, different methods were used for measuring students' usage of metacognitive modelling strategies, giving answers to different research questions. At first glance, the results obtained with the different test instruments do not appear to have any obvious connection. Following the quote of Schraw (2009), the following questions can therefore be formulated:

1. In which aspects do the results of the two methods differ and in which aspects do they match?
2. Can different results be explained by including other data sources?

For answering the research questions, data from different sources are considered, all of them measured in the framework of the MeMo project. So far, the different data sets of the project were analysed using either quantitative methods (questionnaires) or qualitative methods (students' interviews).

Methodological and methodical framework

The research questions posed aim to examine to what extent the same findings can be obtained with both instruments, the questionnaires, and the interviews, or to what extent different results are obtained. In the case of divergent results, a third data source of the project, the videos, will be used to try to find out where the differences come from. This is therefore a validation of the results obtained. Due to the scope of the available data, however, these questions can only be investigated in this paper on an exemplary basis.

Thus, we will concentrate only on the metacognitive area of orientation and planning strategies. While Stillman and Galbraith (1998) have shown that especially groups that did

not spend much time on orientation and planning were successful, other researchers such as Schoenfeld (1992) have shown that thoughtful planning has a significant positive impact on the solution process. Furthermore, this area of metacognitive strategies was identified as one of the invariant factors of individual metacognitive strategies in the empirical analysis of the questionnaires. In the student interviews, this area was the one with the greatest variance and could be reconstructed for all interviewed students. Furthermore, we will only consider the data sets of two students at the second measurement time in the following. At this time, the students worked on the modelling problem presented in Figure 1 in small groups during mathematics lessons.

Sample

The two cases discussed in more detail below are two boys who worked in two different small groups and also came from two different classes. The two cases were selected because the conclusions drawn about them based on their statements in the interview as well as in the self-assessment questionnaires seem concurring in the one case (Furkan) and contradictory in the other case (Robin) at first glance. Furthermore, they were classified differently into the typology of metacognitive behaviour: Due to his statements in the interview, Robin was classified as a distanced metacognitive type, which means that he is sceptical about the use of metacognitive planning strategies and does not use them out of conviction. However, Robin's self-assessments in the questionnaire are very high regarding the metacognitive individual strategies (he ticked the highest value in all individual strategies). Furkan, in contrast, was assigned to the convinced metacognitive type, which means that he is convinced of the usefulness of metacognitive planning strategies and therefore uses them on his own initiative. This classification corresponds with his self-assessment in the questionnaire.

Methods for analyzing data

For answering the research questions, different data sets were used which were analyzed with different methods. Thus, a mixed methods design was used (Buchholtz, 2019).

- In contrast to previous evaluations (Vorhölter, 2018, 2019), for the present questions, the students' self-assessments from the questionnaires were not used as aggregated factor values, but rather their assessments of the individual strategies. The reason for this is that it provides a more differentiated picture of the individual strategies. Furthermore, the metacognitive group strategies for planning were empirically subsumed to the factor of strategies for a smooth process, which is why no factor value existed in this case.
- The interviews were analyzed using case-oriented qualitative content analysis according to Kuckartz (2019). For the selection of the cases considered, the

classification of the cases into the developed typology was used; for the comparison with the data from the questionnaires, the subcodes for planning and orientation, which contain concrete strategies, were used, which were formed during the evaluation (Krüger, 2021).

- Videos were analyzed by using qualitative content analysis according to Kuckartz (2019) and the items of the questionnaire as deductive coding system.

After analyzing each data set separately, results were compared to each other.

Results

In the following, the self-assessments in the questionnaire of the two selected boys, their statements in the interview and the resulting classification in the typology are presented. This is followed by a brief outline of the video scenes in which the planning processes of the small groups can be seen, focusing on the behaviour of the two boys Furkan and Robin. Subsequently, the observations from the videos are compared with the other two data sources.

Case 1: Furkan

Furkan works in a group with two other boys (Dustin and Frederik). He states that he was very satisfied with the cooperation in the group, whereby he interestingly estimates that they worked together the entire time, while the other two state that they divided up at times. Working on the task had been rather easy for him, and he states to have been rather motivated while working on the task.

Furkan's self-assessments related to the first four individual strategies differ in some items from the average of the total sample. He states (as do the other two group members) to a higher degree than the average that he tried to explain the task in his own words and also to obtain missing information, but that he did not note down which information from the task was important for the processing. According to the assessment of all group members, this strategy was also not used in a pronounced manner in the group. Furkan also states that he first thought alone about how he could solve the task before the group started to think about it together.

In the interview, Furkan states that they developed a certain procedure within the group during the course of the intervention. First they look at what information is given and what they still need to research. Then, they think about how they can get the information that they need. To plan the next steps, they use a brainstorming session in which everyone is allowed to contribute their ideas.

It becomes clear that planning the procedure within the group has become an essential part of the working process for Furkan. He thus focuses more on the group, pointing out that everyone is involved in the planning process and can express their ideas, and that the

group's potential can thus be exploited. The accurate representation of the process and the naming of the perceived benefits of planning lead Furkan to be classified as the convinced metacognitive type.

Taking both data sets into account, one can conclude that it is important to Furkan to plan the working process within the group. Furthermore, the planning process was satisfactory in his eyes.

The video starts with the distribution of the modelling problems to the three students. At the beginning of the task processing, Furkan directly begins to read the task text, while Dustin first begins to organize his material and Frederik watches both. About 40 seconds after handing out the worksheet, Furkan finishes reading and starts preparing the written task by writing down the problem title and a date. Already after 1:30 minutes. Dustin suggests extrapolating the area cleared each day to a year, converting the given amount of beer to number of crates, and extrapolating that to a year as well. Furkan questions the procedure and puts it in more concrete terms by saying that it is necessary to know how many liters of beer a crate contains. Felix listens, asks for repetition of what has been said, but initially does not contribute anything of his own. Thus, metacognitive group strategies for planning are used quite obviously by them. It is noticeable that Furkan tries several times to mediate between Frederik and Dustin and is generally concerned about a joint processing. This is also reflected in the fact that he shares his results with the others, waits until they have also calculated the corresponding figures and weighs up the individual ideas for further action against each other or links them with each other (we could do that too). Thus, a productive metacognitive behaviour (Stillman, 2011) can be reconstructed.

If one compares the behaviour shown in the video with Furkan's self-assessments, it is noticeable that Furkan is the one in the group who repeatedly mediates between Frederik and Dustin and brings together the ideas of the other two. Therefore, both his assessments and those of the other two boys regarding cooperation in the group are comprehensible: While the two others state that they did not work together consistently, Furkan, who is always trying to bring things together, states that they did work together consistently. Now, while collaboration does not constitute a metacognitive strategy, Furkan does employ such to initiate this collaboration. Regarding the assessment of identifying needed information from the task text, it should be noted that this is not observed in the video either. Unlike other students, the students of this group do not note down individual values or underline them in the task text but mention them verbally. Therefore, Furkan's self-assessment is correct here. His self-assessment of having initially thought alone about how to solve the task can also be verified by the video: Furkan first reads the task alone and can then very quickly take up Dustin's thoughts on how to proceed and continue them, which makes it clear that he himself must have already had similar thoughts. In summary, it can be stated that Furkan's self-assessments correspond to the observations from the video.

Furthermore, the classification into the typology is also comprehensible on the basis of the videos.

Case 2: Robin

Robin is the only boy working in a group with three other girls. Like Furkan, he estimates the task difficulty as rather easy and was rather motivated at the beginning of the processing, towards the end even very motivated and thus the most motivated (according to his own statements) of the group. He states that he is satisfied with the collaboration in the small group, stating that the group continued to divide at times and that he only worked with individuals.

Robin's ratings are above the overall average in all strategies and also above the ratings of the other group members in almost all ratings (with the exception of the item “We made sure everyone understood the problem”). Similar to Furkan, Robin also rates the group's metacognitive behaviour as less pronounced than his own, but still in the upper range. Therefore, at first glance, Robin appears as a student who is convinced that he engages in a great deal of metacognitive activity, at least on individual level.

Contrary to his self-assessments, Robin was classified as a metacognitively distanced type in the area of planning concerning his group activities. This judgment is based on his statements in the interview, in which it becomes clear that he is rather critical of strategies for planning. For example, he describes that he quickly withdrew from the group's planning phase and started calculating on his own, since the group's stated goal had been to let two girls work first. At the same time, he did not want to wait with the calculating. The reason he gives for his behaviour is that he perceives such planning as unnecessary and rather a waste of time. If such planning would help avoid mistakes in procedure, he would consider it useful.

In contrast to his self-assessments, Robin makes clear in the interview his lack of understanding of the usefulness of metacognitive strategies for planning, although this relates primarily to the planning of joint work in the group. Robin describes that he starts working on the tasks and the mathematical model when he has a first approach. He does not think about every steps of the solution process. Therefore, the question arises at this point whether this discrepancy can be clarified by the video recorded of the group work.

The video recording of the group's working process begins with the handing out of the worksheets. After about five minutes, the teachers asked for reading out the problem together in class. During the student's contribution, Robin begins working on the task by writing something on a piece of paper. Immediately following the class discussion, he invites the teacher to the table and asks her about the market share of the brewery and whether he may assume a 100 percent market share. Furthermore, he asks for the number of bottles per crate.

Robin then continues to work without sharing his considerations with the others. One of the three girls in the group begins to sketch solution steps, with the other two girls listening to her and one also interjecting her own idea. Robin, meanwhile, continues to work independently, but responds briefly to a question about values. At minute ten, i.e. after a good 5-minute work phase by Robin and planning phase by the three other group members, they ask Robin what he is doing. He answers that he is calculating. When asked if he was calculating what the others had planned to do, he answered in the negative. Thus, a form of partial metacognitive blindness could be reconstructed.

The fact that Robin starts working in class while the task is still being discussed and asks the teacher about individual assumptions directly after the discussion suggests that he has his own approach in mind, which he is already implementing – without the other group members. His high ratings regarding the individual metacognitive strategies of having first thought alone about how to solve the task as well as having procured missing information can thus be confirmed from his behaviour shown in the video. To what extent he really recorded which information is still missing and which is given or whether he paraphrased the task in his own words cannot be concluded from the video. However, the independent work on the task gives an indication that he has penetrated the task for himself and identified necessary aspects. While his self-assessments regarding the individual strategies are comprehensible, this is not the case for the group strategies, at least in planning. Robin states that he recorded information together and considered together which steps had to be carried out one after the other. Only partially did they make sure that everyone understood the problem. As described, it can be observed in the video that despite the goal formulation of also giving precedence to the two girls who so far felt "overrun" in the group work, Robin works on his own and does not participate in the group's planning process. Nevertheless, he responds briefly to a question about a value and the group members are all present when he asks the teacher about certain assumptions and values. This means that he probably perceives that the others in the group are planning together and, after all, information is being recorded together (at least mentally). The group itself did not pay attention to whether everyone understood the problem, but the teacher took over this task for the whole class.

In summary, it can be stated that Robin's behaviour shown in the video can confirm his self-assessments regarding the metacognitive individual strategies. For the metacognitive group strategies, his statements paint too positive a picture. However, the classification in the typology can also be confirmed, at least for the area of metacognitive group strategies, as a metacognitive distanced type: Robin virtually blocks strategies that would lead to cooperation in the group or ignores corresponding attempts of his classmates.

Summary and outlook

As already described, the two boys Furkan and Robin were selected for the study, since the findings resulting from the questionnaires and the interviews coincided for Furkan, but diverged at first glance for Robin. Therefore, in relation to both cases, the questions were investigated to what extent the findings from the two methods differed and in which cases they coincided. Furthermore, it was examined to what extent discrepancies could be explained by the inclusion of a third data source, the video recordings of the working process.

In summary, it can be shown that no discrepancies could be found in Furkan from the three sources. Furkan proves to be a reflective and metacognitively convinced type in all three data sources. Robin, on the other hand, must be evaluated as an example of a student in whom the classification in the typology, which was made on the basis of his statements in the interview, does not correspond to his statements in the questionnaire with regard to individual metacognitive strategies nor with regard to metacognitive group strategies. The addition of the video could show reasons for these discrepancies: The classification into the typology could be confirmed by his behaviour in the video. His statements on the metacognitive group strategies in the questionnaire correspond to the behaviour of the group members in the analysed scenes, but Robin had withdrawn from the group process in this phase. His answers in the questionnaire regarding the individual strategies cannot be substantiated by the videos either, as no use of metacognitive strategies could be observed in the video. Robin's goal-oriented work may indicate that he has internalized the use of individual metacognitive strategies to such an extent that they run automatically, and he is only aware of them when he is directly asked about them. However, it may also indicate that the task was so easy for Robin that the use of metacognitive strategies was not necessary (hence his refusal in the interview), but he has learned that the use of them is desirable (hence his rating in the questionnaire).

The following conclusions can be drawn from the above summary thus confirming the problems identified before:

Reliable data in the questionnaire require that students are aware of the use of metacognitive strategies, that metacognitive individual and group strategies are measured separately per different items and that students know which persons they should include in items concerning group work. Thus, for using a questionnaire some prerequisites must be fulfilled: It has proved preferable that the questionnaire has been filled out directly after the completion of a task in order to increase the likelihood that the actual measure of the use of the metacognitive strategies, not metacognitive strategy knowledge, is surveyed (Veenman, 2011a). In addition, care should be taken that the tasks are offered at a subjective intermediate level of difficulty. The occurrence of difficulties leads to the conscious application metacognitive of strategies (Veenman, 2011b; Weinert, 1984). In order to be

able to better evaluate the results of metacognitive group strategies, a supplementary question about which group members collaborated with whom and in which phase should be used.

The interviews give an insight into the students' views. Similar to Stilman's (2004) results, cognitive and metacognitive strategies can be well distinguished from each other, but the differentiation into metacognitive individual strategies and metacognitive group strategies is clearly more difficult because the students do not differentiate in their statements. This leads to another methodological conclusion: When using interviews to elicit views on metacognitive strategies, a deliberate distinction should be made between the individual and the group-specific strategies. Interviewers should thus try to become aware during the interview whether their questions are answered more on according to individual metacognitive strategies or group metacognitive strategies and ask about the other aspect accordingly.

The mere observation of the students' behaviour in the video does not provide any information about individual thinking processes and thus individual metacognition when working in a group cannot be assessed (Schellings et al., 2013). However, the same standard can be applied to the extent of metacognitive behaviour through the evaluation of the behaviour by trained experts.

To sum up, by adding the third data source, it could be highlighted that the type of collaboration in the group and the related answering behavior of the students has a significant influence on the interpretability of the data. This must be taken into account in corresponding evaluations and the instruments used should be adapted accordingly before being used again. At the same time, it has become clear once again, as presented in the statement by Schraw (2009, p. 415) mentioned at the beginning, that measuring instruments must always be chosen with regard to the question to be answered: If the effectiveness of a learning environment for the promotion of metacognitive modelling strategies is to be researched as a whole, then the questionnaire presented can be used; if the promotion of the use of metacognitive modelling strategies for individual students is the focus, then interviews can be used as presented.

References

Artzt, A. F., & Armour-Thomas, E. (1992). Development of a cognitive-metacognitive framework for protocol analysis of mathematical problem solving in small groups. *Cognition and Instruction*, *9*(2), 137–175.

Blum, W. (2015). Quality teaching of mathematical modelling: What do we know, what can we do? In S. J. Cho (Ed.), *The Proceedings of the 12th International Congress on Mathematical Education* (pp. 73–96). Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-319-12688-3_9

Buchholtz, N. (2019). Planning and conducting mixed methods studies in mathematics educational research. In G. Kaiser & N. Presmeg (Eds.), *Compendium for early career researchers in mathematics education* (pp. 131–152). Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-030-15636-7_6

Chalmers, C. (2009). Group metacognition during mathematical problem solving. In R. K. Hunter, B. A. Bicknell, & T. A. Burgess (Eds.), *Crossing divides: MERGA 32 Conference Proceedings* (pp. 105–111). Palmerston North, New Zealand: MERGA.

Cooke, N. J., Salas, E., Kiekel, P. A., & Bell, B. (2004). Advances in measuring team cognition. In E. Salas & S. M. Fiore (Eds.), *Team cognition: Understanding the factors that drive process and performance* (pp. 83–106). Washington, DC: American Psychological Assoc. https://doi.org/10.1037/10690-005

Efklides, A. (2008). Metacognition. *European Psychologist*, *13*(4), 277–287. https://doi.org/10.1027/1016-9040.13.4.277

Gass, S. M., & Mackey, A. (2000). *Stimulated recall methodology in second language research*. Mahwah NJ: Erlbaum.

Goos, M. (2002). Understanding metacognitive failure. *Journal of Mathematical Behavior*, *21*(3), 283–302. https://doi.org/10.1016/S0732-3123(02)00130-X

Goos, M., Galbraith, P., & Renshaw, P. (2002). Socially mediated metacognition: Creating collaborative zones of proximal development in small group problem solving. *Educational Studies in Mathematics*, *49*, 193–223. https://doi.org/10.1023/A:1016209010120

Hankeln, C., Adamek, C., & Greefrath, G. (2019). Assessing sub-competencies of mathematical modelling – Development of a new test instrument. In G. A. Stillman & J. P. Brown (Eds.), *Lines of inquiry in mathematical modelling research in education* (pp. 143–160). Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-030-14931-4_8

Kaiser, G. (2007). Modelling and modelling competencies in school. In C. Haines, P. L. Galbraith, W. Blum, & S. Khan (Eds.), *Mathematical modelling: Education, engineering and economics* (pp. 110–119). Chichester: Horwood Publishing. https://doi.org/10.1533/9780857099419.3.110

Kaiser, G., & Brand, S. (2015). Modelling competencies: Past development and further perspectives. In G. A. Stillman, W. Blum, & M. Biembengut (Eds.), *Mathematical modelling in education research and practice* (pp. 129–149). Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-319-18272-8_10

Krüger, A. (2021). *Metakognition beim mathematischen modellieren. Strategieeinsatz aus schülerperspektive*. Wiesbaden: Springer. https://doi.org/10.1007/978-3-658-33622-6

Kuckartz, U. (2019). Qualitative text analysis: A systematic approach. In G. Kaiser & N. Presmeg (Eds.), *Compendium for early career researchers in mathematics education* (pp. 181–197). Cham, Switzerland. https://doi.org/10.1007/978-3-030-15636-7_8

Leiss, D., Möller, V., & Schukajlow, S. (2006). Bier für den regenwald. Diagnostizieren und fördern mit modellierungsaufgaben. *Friedrich Jahresheft*, *24,* 89–91.

Maaß, K. (2006). What are modelling competencies*? ZDM - Mathematics Education, 38*(2), 113–142. https://doi.org/10.1007/BF02655885

Ng, K. E. D. (2010). Partial metacognitive blindness in collaborative problem solving. In L. Sparrow, B. Kissane, & C. Hurst (Eds.), *Shaping the future of mathematics education* (pp. 446–453). St Lucia, Qld.: MERGA.

Ohtani, K., & Hisasaka, T. (2018). Beyond intelligence: A meta-analytic review of the relationship among metacognition, intelligence, and academic performance. *Metacognition and Learning, 13*(2), 179–212. https://doi.org/10.1007/s11409-018-9183-8

Rogat, T. K., & Adams-Wiggins, K. R. (2014). Other-regulation in collaborative groups: Implications for regulation quality. *Instructional Science*, *42*(6), 879–904. https://doi.org/10.1007/s11251-014-9322-9

Schellings, G. L.M. (2011). Applying learning strategy questionnaires: Problems and possibilities. *Metacognition and Learning, 6*(2), 91–109. https://doi.org/10.1007/s11409-011-9069-5

Schellings, G., van Hout-Wolters, B., Veenman, M., & Meijer, J. (2013). Assessing metacognitive activities: The in-depth comparison of a task-specific questionnaire with think-aloud protocols. *European Journal of Psychology of Education*, *28*(3), 963–990. https://doi.org/10.1007/s10212-012-0149-y

Schoenfeld, A. H. (1992). Learning to think mathematically: Problem solving, metacognition, and sense-making in mathematics. In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 334–370). New York, NY: MacMillan.

Schraw, G. (2009). Measuring metacognitive judgments. In A. C. Graesser, D. J. Hacker, & J. Dunlosky (Eds.), *Handbook of metacognition in education* (pp. 415–429). New York, NY: Routledge.

Schraw, G., & Moshman, D. (1995). Metacognitive theories. *Educational Psychology Review*, *7*(4), 351–371. https://doi.org/10.1007/BF02212307

Schukajlow, S., & Krug, A. (2013). Planning, monitoring and multiple solutions while solving modelling problems. In A. M. Lindmeier & A. Heinze (Eds.), *Mathematics learning across the life span: Proceedings of the 37th Annual Meeting of the International Group for the Psychology of Mathematics Education* (Vol. 4, pp. 177–184). Kiel, Germany: PME.

Schukajlow, S., & Leiß, D. (2011). Selbstberichtete strategienutzung und mathematische modellierungskompetenz. *Journal für Mathematikdidaktik 32*, 53–77. https://doi.org/10.1007/s13138-010-0023-x

Stillman, G. A. (2004). Strategies employed by upper secondary students for overcoming or exploiting conditions affecting accessibility of applications tasks. *Mathematics Education Research Journal*, *16*(1), 41–71. https://doi.org/10.1007/BF03217390

Stillman, G. A. (2011). Applying metacognitive knowledge and strategies in applications and modelling tasks at secondary school. In G. Kaiser, W. Blum, R. Borromeo Ferri, & G. A. Stillman (Eds.), *Trends in teaching and learning of mathematical modelling* (pp. 165–180). Dordrecht, Netherlands: Springer. https://doi.org/10.1007/978-94-007-0910-2

Stillman, G. A., & Galbraith, P. L. (1998). Applying mathematics with real world connections: Metacognitive characteristics of secondary students. *Educational Studies in Mathematics*, *36*(2), 157–194. https://doi.org/10.1023/A:1003246329257

Vauras, M., Iiskala, T., Kajamies, A., Kinnunen, R., & Lehtinen, E. (2003). Shared-regulation and motivation of collaborating peers: A case analysis. *PSYCHOLOGIA – An International Journal of Psychology in the Orient*, *46*(1), 19–37. https://doi.org/10.2117/psysoc.2003.19

Veenman, M. V. J. (2011a). Alternative assessment of strategy use with self-report instruments: A discussion. *Metacognition and Learning*, *6*(2), 205–211. https://doi.org/10.1007/s11409-011-9080-x

Veenman, M. V. J. (2011b). Learning to self-monitor and self-regulate. In P. A. Alexander & R. E. Mayer (Eds.), *Handbook of research on learning and instruction* (pp. 197–218). New York: Routledge. https://doi.org/10.4324/9780203839089.ch10

Veenman, M. V. J., & Elshout, J. J. (1999). Changes in the relation between cognitive and metacognitive skills during the acquisition of expertise. *European Journal of Psychology of Education, 14*(4), 509–523. https://doi.org/10.1007/BF03172976

Volet, S., Summers, M., & Thurman, J. (2009). High-level co-regulation in collaborative learning: How does it emerge and how is it sustained? *Learning and Instruction, 19*(2), 128–143. https://doi.org/10.1016/j.learninstruc.2008.03.001

Vorhölter, K. (2017). Measuring metacognitive modelling competencies. In G. A. Stillman, W. Blum, & G. Kaiser (Eds.), *Mathematical modelling and applications. Crossing and researching boundaries in mathematics education* (pp. 175–185). Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-319-62968-1_15

Vorhölter, K. (2018). Conceptualization and measuring of metacognitive modelling competencies: Empirical verification of theoretical assumptions. *ZDM – Mathematics Education*, *50*(1-2), 343–354. https://doi.org/10.1007/s11858-017-0909-x

Vorhölter, K. (2019). Enhancing metacognitive group strategies for modelling. *ZDM – Mathematics Education*, *51*, 703 – 716. https://doi.org/10.1007/s11858-019-01055-7

Vorhölter, K., Krüger, A., & Wendt, L. (2019). Metacognition in mathematical modeling – An overview. In S. A. Chamberlin & B. Sriraman (Eds.), *Advances in mathematics education. Affect in mathematical modeling* (pp. 29–51). Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-030-04432-9_3

Weinert, F. E. (1984). Metakognition und motivation als determinanten der lerneffektvität: Einführung und überblick. In F. E. Weinert, R. H. Kluwe, & A. L. Brown (Eds.), *Metakognition, motivation und lernen* (pp. 9–21). Stuttgart, Germany: Kohlhammer.